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Science | Sciences
Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
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STOCK ASSESSMENT OF NORTHERN (2J3KL) COD IN 2013

Figure 1. Stock area of northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

Context:

The biomass (ages 3 and older) of the northern cod (Gadus morhua) stock off southern Labrador and eastern Newfoundland (NAFO Div. 2J3KL; Fig. 1) was about 3 million tonnes in the early 1960s. Fishing intensity increased greatly in the 1960s as non-Canadian fleets exploited dense offshore over-wintering aggregations. The stock collapsed to about 0.5 million tonnes by the late 1970s. After extension of jurisdiction in 1977, the stock recovered partially to just over 1 million tonnes in the mid-1980s, but it declined again during the late 1980s and collapsed to an extremely low level by the early to mid-1990s. A moratorium on directed commercial fishing was declared in 1992.

Historically, many Atlantic Cod migrated from over-wintering areas offshore to feeding areas inshore, where they were exploited by the traditional inshore fixed-gear fishery. By the mid-1990s it was apparent that these offshore populations were barely detectable. At the same time, it was recognized that there were aggregations of cod in the inshore in Div. 3L and southern Div. 3K. These inshore populations appeared to be more productive during the 1990s than populations in the offshore. A small fishery directed at these inshore populations was introduced in 1998. Catch rates declined and the directed commercial fishery was closed in 2003. A food/recreational fishery, which had been open for several years, was also closed. Catches during 2003-2005 were limited mainly to bycatch in the Winter Flounder (blackback) fishery.

A stewardship fishery and a recreational fishery for cod were re-opened in the inshore in 2006 and

continued in 2007-2012. This stock is assessed annually. At a framework meeting in November 2010, a conservation limit reference point (LRP) was established for northern cod against which current status and trends can be compared for advice purposes; however, no timelines for rebuilding have been identified by management. The present assessment is the result of a request for science advice from the Fisheries Management (FM) Branch (Newfoundland and Labrador Region). The main objectives were to evaluate the status of the stock and provide scientific advice in accordance with the Sustainable Fisheries Framework.

The current evaluation of the stock was conducted through a regional advisory process (RAP). The meeting was held March 11-14, 2013 in St. John's, NL. Participants included DFO scientists, fisheries managers, and individuals from provincial governments, non-government organizations, the fishing industry, and academia.

SUMMARY

- Reported landings in 2012 were 3,305 t. This included 2,991 t in the stewardship fishery, 272 t in the sentinel survey, and 41 t taken as by-catch. Estimates of recreational landings are not provided for 2012; therefore total catch in 2012 is unknown.
- There is evidence from tagging data that the removals by the recreational fishery are substantial (>50 % of the stewardship fishery landings) in recent years. In addition, sampling of the recreational fishery at sea and on land demonstrates that there is widespread discarding of small fish.
- Accurate catch information is needed to fully evaluate the impact of all removals on stock status.
- Inshore catch rate indices from the Sentinel survey differ among northern, central, and southern areas.
- In the northern area catch rates had been low, but increased substantially in 2012.
- In the central area catch rates remained high, but show no trend during 2008-2012.
- In the southern area catch rates have been at an intermediate level and do not show a trend in recent years.
- Catch rates from fish harvesters' log-books show trends similar to those in the sentinel survey, except log-books show an increasing trend in the central area over the 2011 and 2012 period.
- The DFO autumn research vessel survey indices increased more than threefold during 2003-2008 and 2009, but this increasing trend has not continued in the most recent years.
- The spring research vessel survey index for Div. 3L is more variable than the autumn index for Div. 2J3KL but is generally consistent in terms of trends.
- The research vessel surveys in 2012 show an expansion of fish into southern Div. 2J and northern Div. 3K and continuing low abundance in central and southern Div. 3L.
- Based on a cohort analysis of the autumn research vessel survey data (SURBA; **SUR**vey **BA**sed model), the spawning stock biomass (SSB) has increased from 1 % of the Limit Reference Point (LRP) in 2005 to 15 % of the LRP in 2012.
- SURBA estimates of total mortality were low (<20 %) during 2005-2007, increased to 55 % in 2009 then declined to 26 % in 2012.

- SURBA estimates of recent recruitment show improvement (2005-2009 year-classes); however, recruitment is still much lower than was observed in the 1980s.
- A spring acoustic survey of spawning cod in the Bonavista Corridor (offshore Div. 3KL border) conducted by the Centre for Fisheries Ecosystems Research at Memorial University gave an estimate of spawning biomass of 131,000 t. This is considered a partial estimate because not all of the spawning aggregation was surveyed.
- SURBA projections to 2016 were conducted assuming a range of total mortality rates. SSB in 2016 increases to 21 % of the LRP assuming mortality is 20 % lower than recent levels. SSB remains relatively stable if mortality remains at recent levels. SSB biomass decreases to 10 % of the LRP assuming a 20 % increase in mortality.
- Tagging estimates of mean exploitation rates during 2010-2012 were low and ranged between 2 % and 6 % for all landings combined.
- Estimates of current exploitation rates show that fishery removals are a minor component of total mortality rates and have had little impact on recent stock dynamics. However, in keeping with the DFO fishery decision-making framework incorporating the precautionary approach, removals over the next four years should remain low to promote stock growth.

INTRODUCTION

History of the Fishery

Catches of northern cod increased during the 1960s to a peak of over 800,000 t in 1968, declined steadily to a low of 140,000 t in 1978, increased to about 240,000 t through much of the 1980s, and then declined rapidly in the early 1990s in advance of a moratorium on directed fishing in 1992 (Fig. 2).

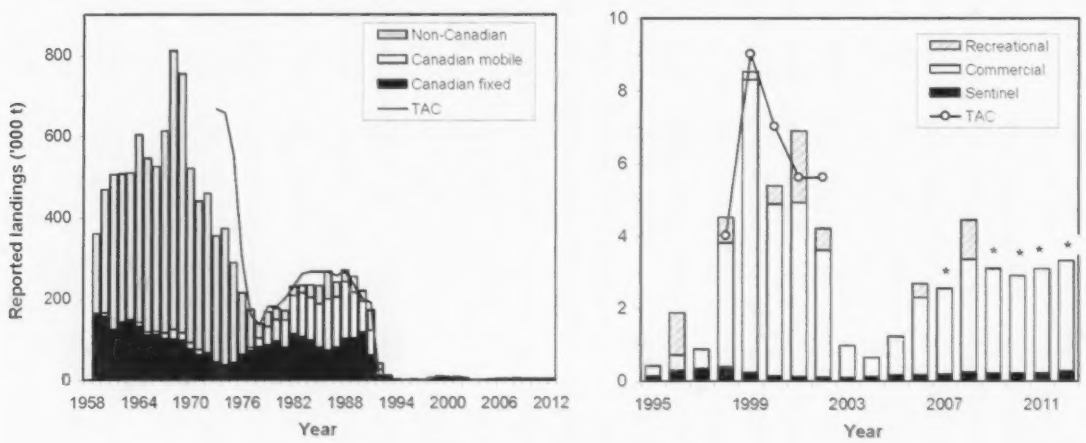

Figure 2. Total Allowable Catches (TACs) and landings (thousands of tons) in 1959-2012. The right panel is expanded to show trends from 1995 onwards. Asterisks indicate that recreational catches in 2007 and 2009-2012 are unknown.

Landings during 1993-1997 came from by-catches, food/recreational fisheries, and DFO-industry sentinel surveys that started in 1995. In addition, landings from 1998 to 2002 also

came from a limited index/commercial inshore fishery restricted to fixed gear and small vessels (<65 ft). The directed commercial and recreational fisheries were closed in April 2003; most of the landings in 2003 came from an unusual mortality event in Smith Sound, Trinity Bay. During 2004 and 2005, substantial by-catches (>600 t) of cod were taken in the inshore, mostly in Div. 3KL, in the Winter Flounder (blackback; *Pseudopleuronectes americanus*) fishery.

A stewardship fishery and a recreational fishery for cod were re-opened in the inshore in 2006 and continued in 2007-2012. Commercial fishers were permitted a fixed annual allowance of cod per license holder ranging from 2,500 lb to 3,250 lb during 2006-2008, and 3,750 lb during 2009-2012. Reported landings in 2012 were 3,305 t. This included 2,991 t in the stewardship fishery, 273 t in the sentinel surveys, and 41 t taken as by-catch, but excluded recreational removals. There are no direct estimates of recreational landings for 2012; therefore, total catch in 2012 is unknown. However, evidence from tagging data shows that the removals by the recreational fishery are substantial (>50 % of the stewardship fishery landings) in recent years. In addition, mean lengths of cod sampled at the dock during the 2008-12 recreational fisheries were generally higher than those sampled at sea, indicating widespread discarding of small fish during recreational fisheries.

The Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) reported that the annual catch of cod by non-Canadian fleets outside the 200 nautical mile limit on the Nose of the Grand Bank (Div. 3L) were 80 t or less during 2000-2009, 61 t for 2010, and 292 t for 2011; catch for 2012 is not yet available.

Landings

Table 1: Reported landings by management year in NAFO Division 2J3KL (nearest thousand metric tons).

Year	62-76 Avg.	77-91 Avg.	98	99	00/ 01	01/ 02	02/ 03	03-06 Avg.	06/ 07[1]	07/ 08[1,2]	08/ 09[1]	09-12 Avg[1,2]	12/ 13[1,2]
TAC	N/A	N/A	4	9	7	6	6	0	-	-	-	-	-
Can. Fixed	88	90	5	9	5	7	4	1	3	3	4	3	3
Can. Mobile	9	84	-	-	-	-	-	-	-	-	-	-	-
Others	405	38	-	-	-	-	-	-	-	-	-	-	-
Totals	502	212	5	9	5	7	4	1	3	3	4	3	3

[1] There was no TAC in the last seven years, but fishers were permitted an annual allowance per license holder of 3,000 lb in 2006-2007, 2,500 lb in 2007-2008, 3,250 lb in 2008-2009, and 3,750 lb in subsequent years.
[2] Does not include estimates of Canadian recreational fisheries or non-Canadian vessels fishing in Div. 3L on the Nose of the Grand Bank.

Species Biology

Historically much of the northern cod stock was highly migratory. They over-wintered near the edge of the continental shelf and migrated in spring/summer to shallow waters along the coast and onto the plateau of Grand Bank. By the mid-1990s these offshore over-wintering populations were barely detectable, but at the same time, there were aggregations of cod in the inshore in Div. 3L and southern Div. 3K. These inshore populations appeared to be more productive during the 1990s than those in the offshore. Inshore populations were small relative

to the populations that historically migrated into the inshore from the offshore during spring/summer.

Tagging studies revealed that during the late 1990s to the mid-2000s the inshore of Div. 3KL was inhabited by at least two groups of cod: (1) a resident coastal group that inhabited an area from eastern Trinity Bay northward to western Notre Dame Bay (Fig. 3) and (2) a migrant group that over-wintered in inshore and offshore areas of Subdiv. 3Ps, moved into southern Div. 3L during late spring and summer, and returned to Subdiv. 3Ps in the autumn. Tagging studies also indicated considerable movement of cod among Trinity Bay, Bonavista Bay, and Notre Dame Bay.

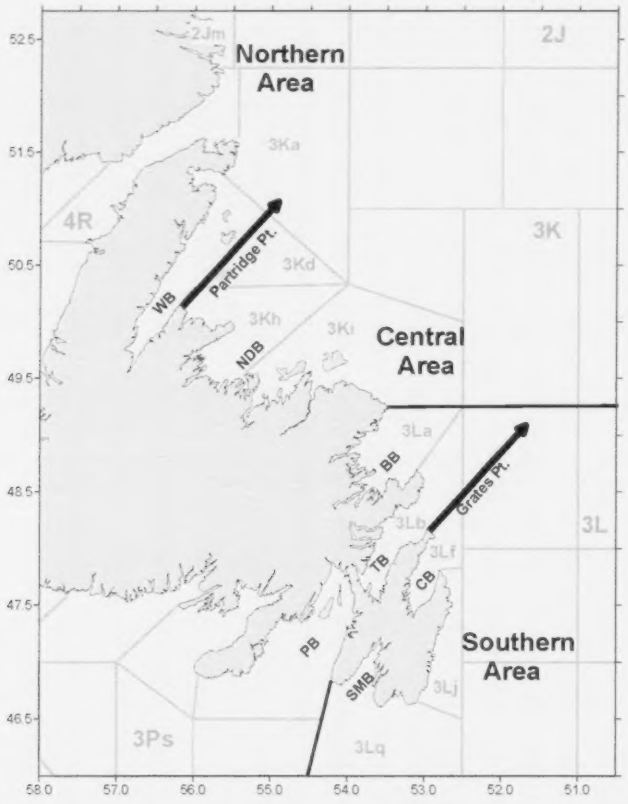

Figure 3. Eastern Newfoundland indicating the locations of the inshore northern, inshore central and inshore southern areas. Major bays are indicated: White Bay (WB), Notre Dame Bay (NDB), Bonavista Bay (BB), Trinity Bay (TB), Conception Bay (CB), and St. Mary's Bay (SMB); Placentia Bay (PB) is in Subdivision 3Ps. Grey lines delimit boundaries of statistical unit areas (i.e., 3Ka, 3Kd, etc.) referred to in the text.

The status of cod in the offshore has improved in the past decade and the shoreward seasonal migration pattern observed prior to the moratorium did take place during recent years. Overwintering inshore aggregations, such as those observed in Smith Sound, Trinity Bay, have diminished and most of the stock now appears to overwinter in the offshore, similar to the pre-moratorium period. The offshore biomass of cod in Div. 2J3KL is low but increased during 2003-2008 and remains near the 2008 level; the current contribution of offshore cod to the inshore biomass during summer is likely substantial.

Cod off Labrador and eastern Newfoundland grow slowly compared with individuals in the eastern Atlantic, the Flemish Cap (Div. 3M), and further south in the western Atlantic. Since the late 1980s females have been maturing at about age 5, which is younger than in previous years.

Small cod tend to feed on small crustaceans; medium-sized cod feed on larger crustaceans and small fish; and large cod feed on medium-sized fish and crabs. Capelin (Mallotus villosus) in particular has historically been an important part of the annual diet.

Ecosystem Information

During the late 1980s and early 1990s the fish community in the Newfoundland and Labrador large marine ecosystem collapsed. This collapse was more dramatic in the northern regions and involved commercial and non-commercial species and included Capelin, the keystone forage fish in this ecosystem. It was also during this period, that important increases in shellfish species (e.g., Northern Shrimp, *Pandalus borealis*) took place.

During 2003 to 2007 there was an increasing trend in the fish biomass in Div. 2J3KL; some components of the fish community (e.g., piscivores such as Atlantic Cod, Greenland Halibut *Reinhardtius hippoglossoides*, and Atlantic Halibut *Hippoglossus hippoglossus*) and large benthivores (e.g., American Plaice *Hippoglossoides platessoides*) showed some positive signals. These were the first significant changes observed in the fish component of ecosystem structure since the collapse, and coincided with an improvement in Capelin biomass during this period. The most recent (2011) ecosystem information indicates that the overall biomass level of the fish community has shown a modest increase from the level reached in 2007-2008, but this overall increase is essentially driven by planktivores-piscivores (e.g., redfish *Sebastes* spp.), while other fish functional groups remain at the levels attained by 2008. Overall, despite the increases observed in the biomass of the fish community since the low point reached in the 1990s, the fish community still remains at a significantly lower level in comparison to the pre-collapse period.

Physical Oceanography

The marine environment off Labrador and eastern Newfoundland experienced considerable variability since the start of standardized measurements in the mid-1940s. A general warming phase reached its maximum by the mid-1960s. Beginning in the early 1970s there was a general downward trend in ocean temperatures, with particularly cold periods in the early 1970s, early to mid-1980s and early 1990s. Ocean temperatures have been above normal for the past decade, reaching highs in 2006, declining to more normal values in 2007-2009, then increasing to record highs in 2011, before decreasing slightly but remaining above normal in 2012. Salinities in 2009-2012 have been fresher than normal. The area of the cold intermediate layer (CIL) on the Newfoundland shelf was at a record low in 2011 but expanded slightly in 2012.

The impact of these oceanographic changes on cod population dynamics is difficult to determine. Cod in this area can be more productive when water temperatures are toward the warm end of the regional norm. Cod somatic growth values were among the highest in the time series in Div. 3KL when temperatures were approaching the peak of 2011-2012. Cod recruitment rate (R/SSB) also shows a weak but positive correlation with a composite climate

index derived from a suite of meteorological, ice and ocean temperature and salinity time series.

Ocean Productivity

Bi-monthly ocean colour imagery and oceanographic data indicate a decline in standing stocks of marine phytoplankton (primary producers) across the Newfoundland and Labrador Shelves in 2012. Timing indices of the spring bloom suggest a trend toward earlier and shorter production cycles. Indices of primary and secondary production from seasonal oceanographic surveys have remained relatively stable over the past decade and in some cases have trended upwards (e.g., copepod abundance) that may support feeding of early life stages of northern cod. Preliminary analysis indicated a weak positive association between the *Calanus finmarchicus* abundance anomaly and the cod recruitment rate (R/SSB) and this relationship requires further exploration. Long-term changes in primary and secondary producers based on the Continuous Plankton Recorder indicate increased standing stocks of phytoplankton and zooplankton during the 2000s and recent years although certain cold-water-adapted calanoids (*Calanus hyperboreus*) and macro-zooplankton such as euphausiids have declined on the southern and northern Newfoundland Shelf.

Predators

Predation is an important source of natural mortality and cod are preyed upon by a changing suite of predators at various stages in their life history, from egg through to mature adults. Pre-recruit cod are eaten by squid, many species of groundfish, including larger cod, and some species of birds. Larger juveniles are eaten by seals and larger groundfish. Large cod probably have few natural predators; Harp Seals (Phoca groenlandica) have been observed preying upon them by belly-feeding in the inshore, but the overall magnitude of this phenomenon is not known.

Studies on the role of Harp Seal predation on ecosystem dynamics are ongoing. The Harp Seal population is currently near the highest levels observed since monitoring began almost 60 years ago. The 2012 population estimate is 6.9 million individuals. Some populations of cetaceans have also increased. Collectively marine mammals consume huge quantities of prey and have the potential to exert a strong influence on ecosystem dynamics including cod populations, directly through predation as well as indirectly by consuming key prey such as Capelin and shrimp.

The quantity of cod estimated to have been consumed by Harp Seals has increased since the late 1980s due, primarily, to increased occurrence of Atlantic Cod in near-shore diet samples. Estimates of total Atlantic Cod consumption by Harp Seals are highly imprecise because of lack of diet data, especially for the offshore. However, analysis from a biomass-based model has been used to explore the impact of fishing, Capelin removals, and predation by Harp Seals on trends in Div. 2J3KL cod stock biomass. Predation by Harp Seals was considered over a wide range of consumption estimates, and results indicate that seal predation is not an important driver of northern cod stock dynamics. This model also indicates that Capelin availability and fishing on cod have had a strong influence on the population dynamics of Div. 2J3KL cod in the past.

Consumption of cod and key prey by other predators such as other fish species and seabirds, may also be substantial, but has not been thoroughly investigated. There is a high level of uncertainty surrounding the overall impact of these predators on cod population dynamics.

Prey

Both Capelin and Pandalus shrimp appear as main prey for cod based on analysis of cod stomachs sampled during autumn research vessel (RV) surveys. During the 1980s and early 1990s Capelin was the main prey in the autumn diet of cod. In recent years, Pandalus shrimp has become a key prey, increasing its contribution to the diet of cod over time. This increasing trend started in the late 1980s, but became more important in the mid-1990s; this coincided with the increase of Pandalus shrimp in the environment. The RV biomass index of Pandalus shrimp increased significantly from the early 1990s until the mid 2000s, but has declined since 2006-2007 reaching levels similar to those observed in the mid-1990s by 2010; the biomass index in 2011-2012 is at levels similar to or slightly above the 2010 level.

An index of offshore Capelin biomass, based on a spring Div. 3L hydro-acoustic survey, indicates that Capelin biomass was high in the 1980s, but dropped dramatically in the early 1990s and has remained low. This general pattern of change in Capelin availability appears to be reflected in the cod diet. Although the Div. 3L hydro-acoustic survey indicated a slight increase in offshore Capelin biomass in 2007-2009 relative to levels during the 1990s and early 2000s, the biomass was still far below what it was in the 1980s; nonetheless, the timing of this improvement in Capelin coincided with recent increases observed in biomass of cod in portions of the offshore. In 2010 this index showed a sharp decrease in Capelin biomass, and is the lowest estimate in the entire survey series. The 2011 and 2012 estimates are higher than 2010, but still an order of magnitude below the 1980s. Capelin were more widely distributed in 2011 and 2012 having shifted from the shelf break onto the shelf and northward from Div. 3K into Div. 2J during autumn.

Both shrimp and Capelin are important prey for cod and other groundfish species. Capelin are at a low level but show some positive signs in terms of expansion of distribution, whereas shrimp have declined. A combined low availability of two major forage species in the ecosystem could compromise the potential for recovery of cod in particular, and the groundfish community in general.

ASSESSMENT

In this assessment a cohort analysis of autumn RV catch rate data was used to infer trends in the overall status of the stock. Trends in indices and harvest rates inferred from tagging studies were also examined. Total landings are unknown and therefore catch-based analytical models such as sequential population analysis (SPA) could not be used.

Sources of data

The main sources of data for this assessment are as follows: Indices of abundance, biomass and other biological characteristics are obtained from multi-species RV bottom-trawl surveys conducted by DFO in the whole of Div. 2J3KL during the autumn and in Div. 3L during the spring. Information on recruitment and total mortality is obtained from analysis of catch rate at age in the autumn surveys. Recaptures of conventionally tagged cod released inshore prior to 2012 and offshore in March 2008, combined with detections of acoustically tagged cod released

offshore in March 2008, were used to estimate exploitation rates and investigate migration patterns.

Indices of abundance are provided by DFO-Industry fixed-gear sentinel surveys in the inshore. Fixed-gear sentinel surveys are conducted by two traditional gears; gillnets of 5½ inch mesh and line-trawls, and a non-traditional 3¼ inch mesh gillnet, which is intended to provide information on young fish. Logbooks from vessels less than 35 feet for post-moratorium fisheries were also examined to investigate area-specific inshore catch rate trends. Tagging studies initiated in 1997 and continued during 2006-2012 provide information on exploitation, distribution, and migration. Hydro-acoustic surveys were conducted in Smith Sound in winter and spring 1997-2004 and 2006-2011, but were not conducted in 2012. A spring acoustic survey of spawning cod in the Bonavista Corridor (offshore Div. 3KL border) was conducted by the Centre for Fisheries Ecosystems Research at Memorial University. An annual telephone survey of fish harvesters' observations is conducted by the Fish, Food and Allied Workers (FFAW) Union. Information on the relative abundance of young cod (ages 0 and 1) is provided by beach seine studies in Newman Sound, Bonavista Bay. Information on the size and/or age composition of the catch is obtained from lengths and otoliths collected from cod sampled at ports and at sea during stewardship, Sentinel and recreational fisheries. A DFO-Industry bottom-trawl survey using small (<65 ft) commercial vessels was conducted annually during July-August 2006-2011, but was discontinued in 2012. This inshore trawl survey provided information on the relative abundance, age composition and distribution of cod inhabiting the coastal and nearshore area of Div. 2J3KL during summer.

Stock Trends

Bottom-trawl surveys

The abundance and biomass indices from the autumn RV surveys during 2010-2012 are 8 % and 10 %, respectively, of the average during the 1980s (Figs. 4 and 5). These indices increased during 2005-2009. The increasing trend has not persisted although the 2012 values for both indices are among the highest observed during the post-moratorium period.

The biomass index from the spring RV survey of Div. 3L is more variable (Fig. 6) but shows broadly similar trends to the biomass index from the autumn RV surveys.

The autumn offshore RV survey abundance and biomass (Figs. 4 and 5) has been concentrated adjacent to the Div. 3K/3L boundary during 2005-2011 and showed slight expansion into northern Div. 3K and southern Div. 2J in 2012.

In 2004, the autumn survey did not complete a portion of northeastern Div. 3L that includes seven strata where cod have often been found at higher density in previous surveys. The survey estimate for 2004 is probably low.

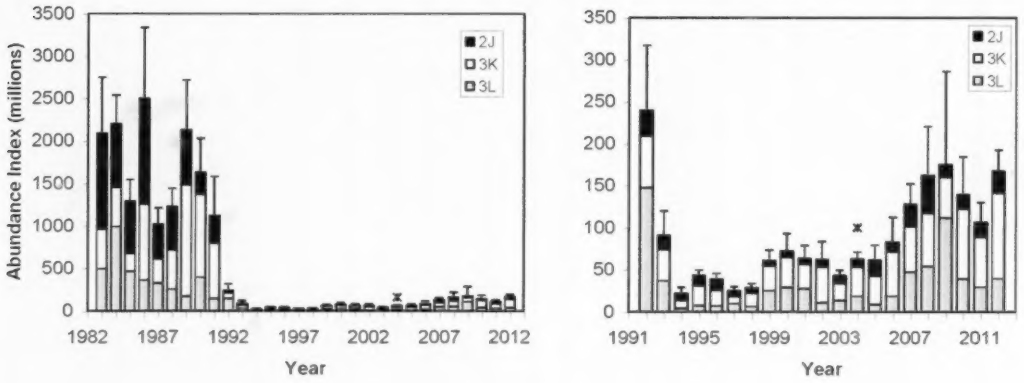

Figure 4. Offshore abundance index (+2 SE's) from autumn RV surveys in Div. 2J3KL. The right panel is expanded to show trends from 1992 onwards. Asterisks indicate partial estimates from incomplete survey coverage of Div. 3L in 2004.

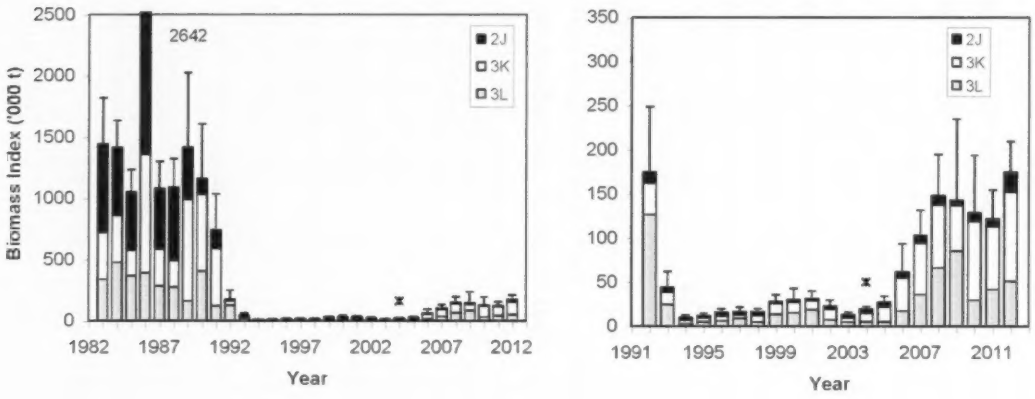

Figure 5. Offshore biomass index (+2 SE's) from autumn RV surveys in Div. 2J3KL. The right panel is expanded to show trends from 1992 onwards. Asterisks indicate partial estimates from incomplete survey coverage of Div. 3L in 2004.

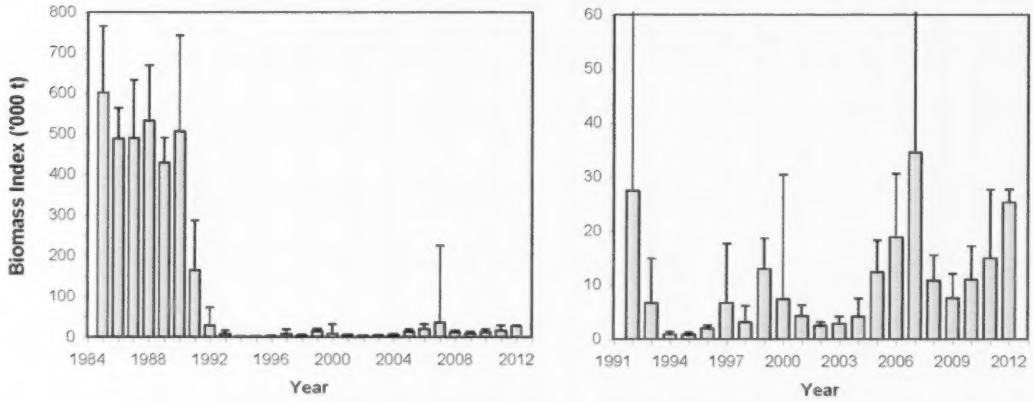

Figure 6. Offshore biomass index (+2 SE's) from spring RV surveys in Div. 3L. The right panel is expanded to show trends from 1992 onwards.

Some of the autumn RV surveys have extended well beyond their normal time and into the winter because of vessel problems. In addition, in some years coverage in some regions was sparse. These changes add uncertainty to survey estimates of mortality rates, abundance, and biomass. The autumn 2012 RV survey was completed on time and all strata were fished.

The SSB index from the autumn RV survey was low for several years after the 1992 moratorium, but increased during 2005-2008 (Fig. 7). The increasing trend has not continued and subsequent values (2009-2012) show no clear trend. The average SSB index during 2010-2012 is 12.5 % of the average in the 1980s. The 2012 SSB index value is 16 % of the average in the 1980s.

Information on recruitment and mortality is derived from mean catch rate-at-age during the autumn RV surveys.

Year-class strength in the offshore in the 1990s and 2000s has been poor compared to the 1980s. The number of young fish (ages 3 and 4) in the offshore survey in the 1990s and 2000s has consistently been much lower than during the 1980s (Fig. 8).

The overall age structure of survey catches has been progressively expanding since 2005, with the 2001 and 2002 year-classes well represented in survey catches in 2012 at ages 11 and 10, respectively.

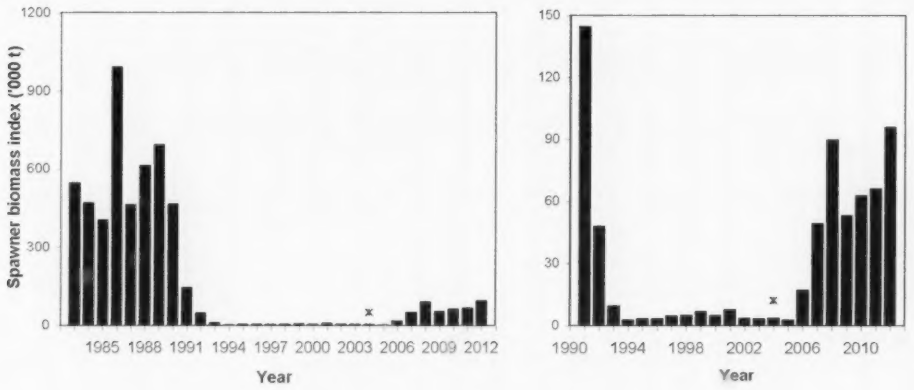

Figure 7. Offshore spawning stock biomass index from autumn RV surveys in Div. 2J3KL. The right panel is expanded to show trends from 1991 onwards. Asterisks indicate partial estimates from incomplete survey coverage of Div. 3L in 2004.

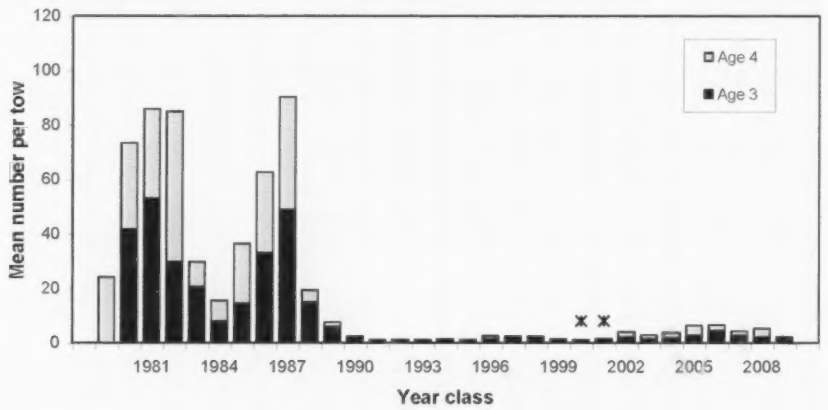

Figure 8. Abundance of the 1979-2009 year-classes at age 3 and age 4 in the offshore of Div. 2J3KL from the autumn RV surveys. Asterisks indicate partial estimates for the 2000 year-class at age 4 and the 2001 year-class at age 3 due to incomplete survey coverage of Div. 3L in 2004.

The total mortality rate (*Z*) (ages 4-6) was low in the 1980s, but was at a high level (*Z*>0.6, i.e., >45 % per yr) from the early 1990s to the mid-2000s, with peaks during the early 1990s and early 2000s (Fig. 9). This high level of mortality has been a major impediment to stock recovery. Total mortality declined substantially during 2003-2006, resulting in an expansion in the age composition, and this has been an important factor in the recent increase in total biomass and SSB. Estimates of *Z* have been highly variable in the past four years increasing to >0.8 during 2010-11 then declining to much lower levels in 2012. During 2010-2012 the value of *Z* for ages 4-6 averaged 0.57, which corresponds to 44 % mortality per year.

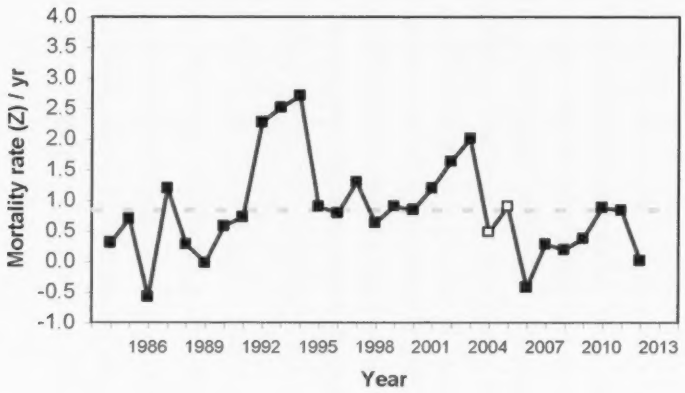

Figure 9. Trends in total mortality rate (Z) of cod aged 4-6 calculated using data from autumn RV surveys in the offshore of Div. 2J3KL. For example, the value in 1996 is the mortality experienced by the 1991-1989 year-classes from ages 4-6 in 1995 to ages 5-7 in 1996. The dashed line is the time-series average (Z = 0.84 which corresponds to 57 % mortality per year). Open symbols indicate estimates based on an incomplete survey in 2004.

The above information on trends in abundance/biomass, recruitment and mortality are based on analysis of observed catch rate-at-age data from the DFO autumn RV surveys. These data (ages 2-12, 1983-2012, excluding 2004) have also been evaluated with a cohort analysis (SURBA model) which produces relative estimates of stock size. This analysis indicates that the recent increasing trends in total biomass and SSB have not continued (Fig. 10, lower panels). Total biomass increased during 2004 to 2009 but was unchanged in 2010-2012. SSB increased from 2004 to 2008, but has since been unchanged. The 2004 RV survey was excluded in this analysis due to incomplete survey coverage.

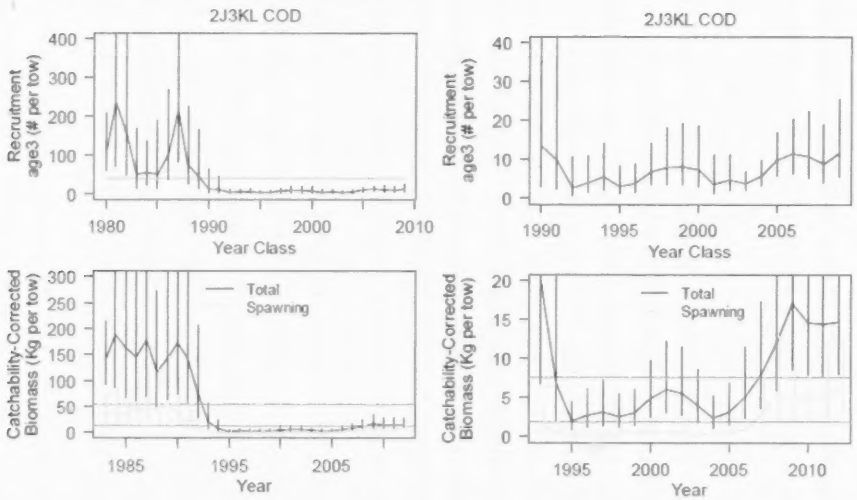

Figure 10. Trends in recruitment (age 3, upper panels) and biomass (ages 2-8) and SSB (lower panels, dashed line) estimated from cohort analysis of autumn RV survey data. Error bars are 95 % confidence intervals. Horizontal lines indicate time-series average. The right panels show the recent time period with the y-axis re-scaled.

Cohort analysis indicates that the relative strength of all year classes produced since 1989 are below the time series average (Fig. 10, upper left panel). Recruitment has shown marginal improvement (2005-2009 year-classes (Fig. 10, upper right panel) and these are now contributing to the spawning biomass; however, recruitment is still much lower than was observed in the 1980s. The estimates for the most recent year classes are based on few data and are more uncertain.

A conservation LRP (biomass limit reference point, Blim) has been established for northern cod (DFO 2011b). Estimated SSB has been well below the LRP since the early 1990s. The estimate of 2012 SSB from the cohort analysis is 15 % of the LRP (Fig. 11).

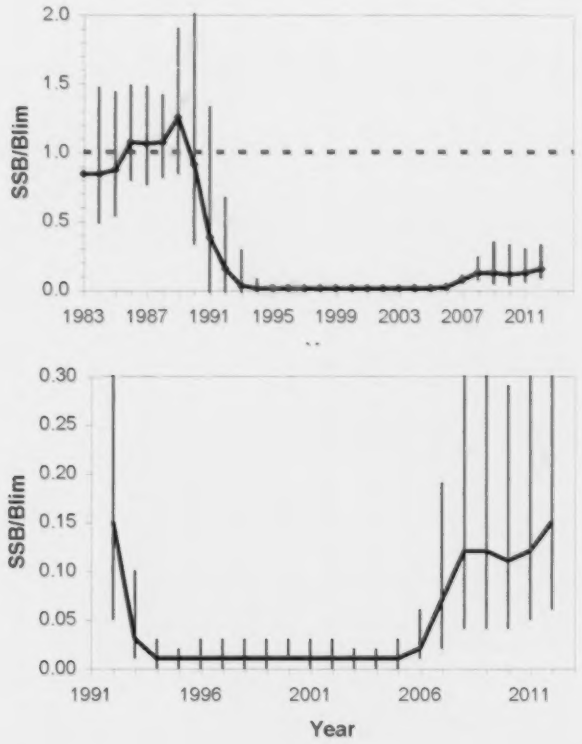

Figure 11. Trends in SSB relative to the LRP (B_{lim}) based on cohort analysis of autumn RV survey data. The upper panel shows the full time series (1983-2012) and the lower panel the more recent (1992-2012) period. Error bars are 95 % confidence intervals.

Estimates of Z (for ages 2-4 and ages 5-11) from the cohort analysis indicate that the annual instantaneous rate of mortality increased during 1989-1993, then declined and remained stable (Z~0.5, i.e., ~38 % per year) during 1994-2000 (Fig. 12). Total mortality declined substantially during 2003-2005 and remained low (Z<0.2, i.e., <18 % per year) to 2007. This low Z has been an important factor in the recent increase in total biomass and SSB. Total mortality increased in 2009 and 2010 (Z~0.5, i.e., ~38 % per year) but diminished in 2011-2012.

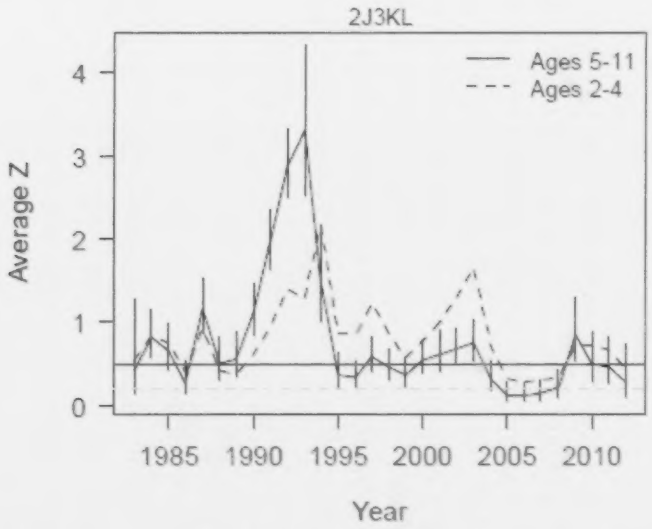

Figure 12. Trends in total mortality rates (Z) for two age groups of cod estimated from cohort analysis of autumn RV survey data. The horizontal lines indicate values of Z=0.5 (solid line) and Z=0.2 (grey dashed line) which correspond to annual mortality rates of 39 % and 18 %, respectively. Error bars are 95 % confidence intervals.

Projections

Projections to 2016 were conducted assuming future total mortality rates were within ±20 % of current values (i.e., the 2010-2012 average; Z=0.46 or 37 % annual mortality) and recruitment was the average of the past three years (2010-2012). Results indicated that 2016 SSB will increase to 21 % of the LRP if total mortality is reduced by 20 %, but will remain relatively stable if mortality remains at current levels. SSB in 2016 is projected to decrease to 10 % of the LRP if total mortality is 20 % above current values.

Tagging

Offshore

Offshore cod were captured and released with conventional and acoustic tags in deep water (>330 m) on the outer edge of the continental shelf in Div. 3K during March 2008.

In the summer and autumn of 2008-2010, offshore tagged cod were recaptured inshore in the recreational and stewardship fisheries; recaptures were widely distributed throughout Div. 3K and Div. 3L. Offshore cod with acoustic tags were also detected on receiver arrays in near-shore areas of Div. 3KL during 2008, 2009 and 2010, and >27 % of those released in 2008 have now been detected inshore. These results indicate that cod from the offshore showed the traditional pre-moratorium migratory pattern, and migrated to the inshore of Div. 3KL during summer 2008-2010, rendering them vulnerable to inshore fisheries. The exploitation rate of offshore cod in the inshore, based on tag returns, ranged between 2 % and 6 % during 2008-2010 from all fisheries combined (stewardship, sentinel, recreational, and by-catch). No conventional tagging as been conducted in the offshore since 2008.

Inshore

Information from recaptures of conventionally tagged cod released in various inshore regions of Div. 3KL during 1997-2012 was used to estimate average annual exploitation (harvest) rates. During the recent (2009-2011) period a total of 7,300 tagged cod were released, mostly during July-October when migratory offshore cod would be inshore.

Exploitation rates from inshore tagging were consistently low, ranging between 2 % and 6 % during 2010-2012 from all fisheries combined (stewardship, sentinel survey, recreational, and by-catch).

The reporting rate of tags from commercial fishers during 2006-2012 ranged from 63 % to 71 %; the 2012 estimate was 65 %. A constant but lower reporting rate of tags was estimated for recreational fishers during 2006-2012 (49-53 %); the 2012 estimate was 49 %. Lower reporting rates of tags add uncertainty to the estimates of exploitation rates from tagging and the analyses of movement patterns and stock structure.

Hydroacoustic survey of the Bonavista Corridor

An acoustic survey of the Bonavista Corridor extending over an area of approximately 13,000 km^2 was conducted by the Centre for Fisheries Ecosystems Research at Memorial University during May 2012 using the RV *Celtic Explorer*. Total abundance within the surveyed area was derived from acoustic data and length and age composition from two fishing sets conducted using a G.O.V. trawl. Total abundance was 61 million fish (38-93 million, 95 % CI) with an estimated spawning biomass of 131,000 t (82,000-199,000 t, 95 % CI). These are considered partial estimates because the survey had insufficient time to delineate the southern and northern extents of the aggregation.

Numbers at length and age in the spring acoustic survey were broadly similar to those found in the autumn DFO RV survey conducted in December 2012 in the same area. The acoustic survey targeted a spawning aggregation and reported fewer younger (i.e., < age 5) cod and more older (ages 8+) cod than the autumn DFO RV survey. The 2002 year-class at age 10 was strongly represented in samples of the spawning aggregation.

Biological Information (Offshore)

The information in this section comes from sampling during the DFO autumn offshore RV surveys.

Growth

Length-at-age and weight-at-age in 2011 and 2012 were generally above average in all Divisions. For Div. 2J3KL combined, mean weight-at-age in 2011 and 2012 were among the highest in the time series and well above the weights in 2009 and 2010.

Condition

Condition of cod, as measured by both gutted weight (relative condition) and liver weight (relative liver condition), decreased in 2012 relative to the high levels in 2011. However, both indices of condition were among the higher values in the time series in each Division.

Maturity

The proportion of female cod that are mature at young ages has increased over time particularly among cohorts produced from the late 1980s onward. For example, the percentage of age 6 cod that are mature averaged about 50 % in the 1980s, but has increased to about 80 % since the early 1990s. Values for age-at-maturity among recent cohorts (2006-2008) are based on fewer ages and are more uncertain. Males generally mature about one year younger than females and show a similar trend over time. The reasons for the change towards earlier age-at-maturity are not fully understood. The change may have a genetic component and partly be associated with high levels of mortality and low stock size.

Cod growth rates and condition show considerable annual variability, but in the past two years have been relatively high. These components of stock productivity are generally improving, but others such as recruitment and survival remain lower than were observed in the early 1980s when biomass and harvests were much larger. Age at maturity also remains low.

Inshore Catch Rate Indices

Due to differences in dynamics as evidenced by catch rate trends and results from tagging, information for the inshore is presented separately for three inshore areas: 1) a northern area (Div. 2J and northern Div. 3K); 2) a central area (southern Div. 3K and northern Div. 3L) and 3) a southern area (southern Div. 3L) that is largely dependent on migrant fish, from Subdiv. 3Ps and possibly other offshore areas. The dividing lines for these areas are Partridge Point at the western side of Notre Dame Bay and Grates Point at the eastern side of Trinity Bay (Fig. 3).

Commercial (Stewardship) Fishery

Catch and effort data for the <35 feet sector, from log-books for the 1998-2002 commercial fishery and the 2006-2012 stewardship fishery, were examined (Fig. 13). Median gillnet catch rates (kg/net) dropped slightly during 2009 and/or 2010 but increased in 2011-2012 in each region. The trend in catch rates from log-books is broadly consistent with sentinel survey information (see next section). Commercial catch rates are expressed in terms of weight and recent increases are partly influenced by more older (and therefore heavier) cod in the stewardship fishery catches in 2011 and 2012. Commercial fishers can also use larger mesh sizes (6.0 inch and 6.5 inch mesh) which select larger cod, whereas sentinel fishers are restricted to 5.5 inch mesh.

Sentinel Surveys

Sentinel catch rates in the northern area were typically much lower than those in other areas, but increased after 2004 (Fig. 14, upper panel). Catch rates increased substantially in the past two years and in 2012 are comparable to those in the central area. Catches in this area depend on seasonal immigration of fish from offshore regions, including Div. 2J and Div. 3K.

Sentinel catch rates in the central area show no trend during 2008-2012, but have typically been higher than those in other areas (Fig. 14, middle panel). Catches in this area were formerly dependent on resident inshore components and seasonal migrants from the offshore. The biomass in the offshore adjacent to the central area has improved in recent years and migratory offshore fish likely dominate recent catches.

Sentinel catch rates in the southern area have been at an intermediate level and do not show a trend in recent years (Fig. 14, lower panel). Catches in this area are partly dependent on seasonal immigration of fish from the offshore of Div. 3KL, and from Subdiv. 3Ps where the stock had declined but is now improving.

Sentinel survey sites using line-trawl are also used to develop a catch rate index for the central area; however, this index (not shown) is based on much fewer data, shows high variability and has trends that are inconsistent with the gill net index.

The age structure of cod captured in recent inshore fisheries (stewardship, recreational and sentinel survey) and in the offshore autumn DFO RV survey are consistent, showing an expansion of the age structure and consistent tracking of the 2002 year-class through to age 10 in 2012. The 2002 year-class at age 10 was also strongly represented in the Bonavista Corridor spawning aggregation surveyed in spring 2012.

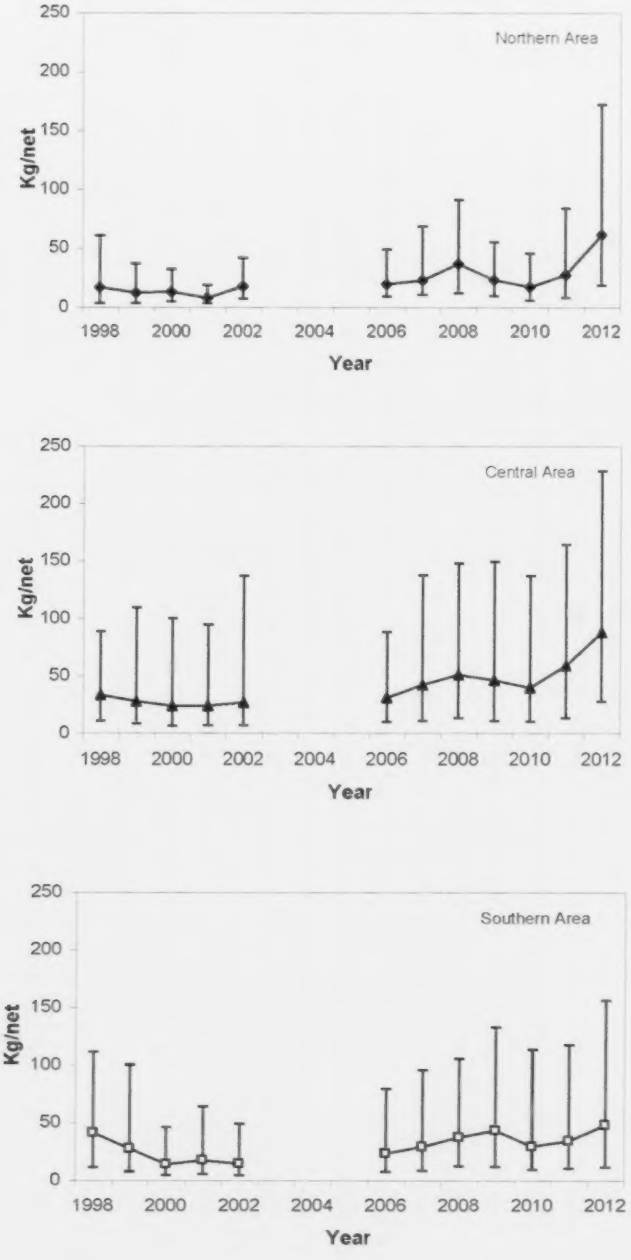

Figure 13. Median catch rates, with 10th and 90th percentiles, from log-books for the <35 ft vessel sector using gillnets in each of the three inshore areas in Fig.3. There was no directed fishery in 2003-2005.

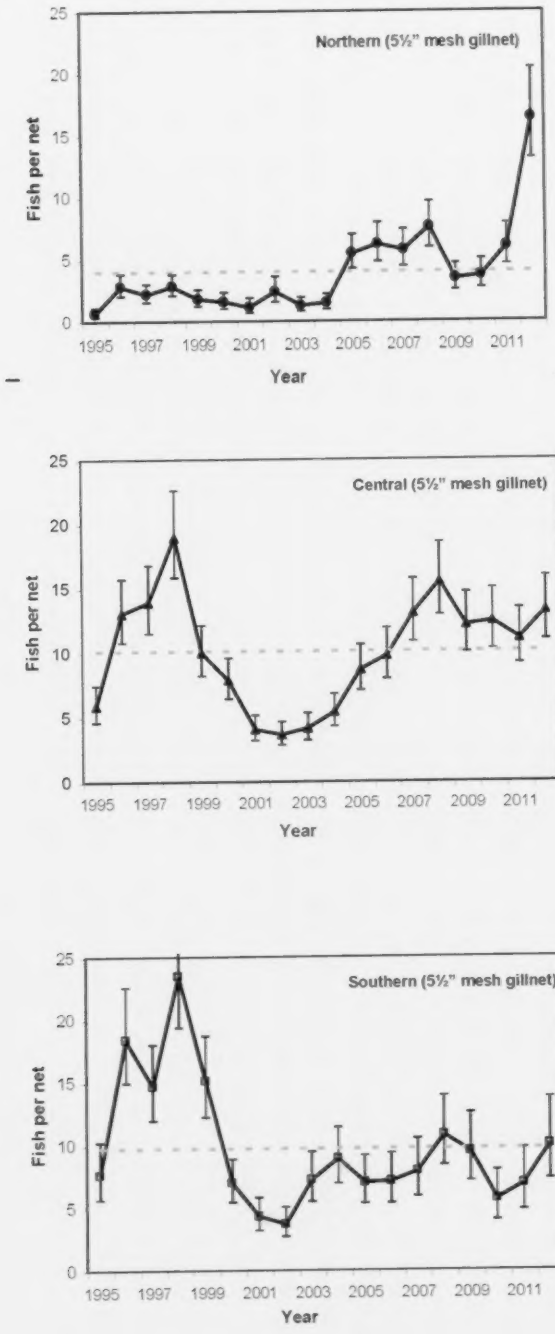

Figure 14. Standardized catch rates, with 95 % confidence limits, from sentinel surveys using gillnets (5.5" mesh) for each of the three inshore areas as depicted in Fig.3. Series means are plotted as dashed lines.

Sentinel Survey: Recruitment

An inshore recruitment index was derived from catch rates of juvenile cod (ages 3 and 4) during the sentinel survey (Fig. 15). The 1992, 2000, and 2002 year-classes are well above the average of 1992-2007. The four most recent year classes are estimated to be average (2009) or weaker than average (2006, 2007, and 2008).

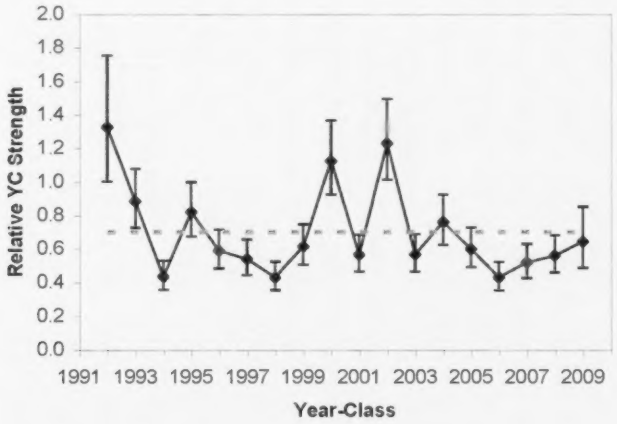

Figure 15. Standardized year class strength from sentinel survey catch rate data for ages 3 and 4 using 5½ inch and small mesh (3¼ inch) gillnets for the inshore central area. The dashed grey line is the time-series average.

Beach seine surveys: Pre-recruitment

Information on the strength of recent year-classes is available from a beach seine survey in Newman Sound, Bonavista Bay (northern Div. 3L). This survey catches cod mainly of ages 0 and 1, with age 0 being much more strongly represented. These pre-recruit ages are not adequately represented in other indices. The information on age 1 from this study has been broadly consistent with the sentinel indices for the same year-classes (1995-2003) at older ages, but the correlation is less clear after 2003. Most of the year classes from 2003 onwards are weak at age 1, the exceptions being the 2007 and 2010 year classes which are above average (Fig. 16). In addition, numbers of age 0 cod caught at several sites in Newman Sound during 2012 surveys were much higher than average and the second highest in the time-series. However, survival to age 1 can be highly variable; therefore, the strength of the 2012 year-class is currently uncertain.

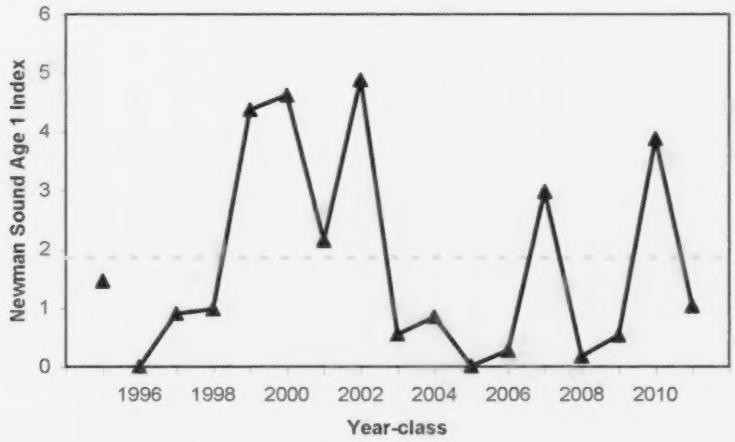

Figure 16. Trends in the numbers of age 1 cod from beach seine surveys in Newman Sound. Series mean is plotted as dashed line.

Overall, recruitment information from the inshore (sentinel survey and pre-recruits) in the recent period is not consistent with the trends observed for the offshore (autumn DFO RV survey and SURBA analysis) with the latter showing all year classes after 2005 slightly improved. The recruitment information for the offshore covers a much broader area and range of ages and is therefore considered to be a better indicator of recent recruitment trends for the stock as a whole.

Hydroacoustic Surveys of Smith Sound

Winter hydroacoustic studies were conducted mostly during January-March in Smith Sound in western Trinity Bay (Fig. 3) starting in 1999. Biomass indices increased to a peak of about 26,000 t in 2001 and then declined to 18,000 t in 2004. The surveys were suspended in 2005 but resumed in 2006. Biomass indices were stable in 2006 at 16,500-18,500 t, but declined to 14,000 t in 2007 and to 7,200 t in 2008. The estimated biomass from surveys conducted in April 2009, June 2010, and February 2011 were much lower, i.e., 600 t, 300 t, and 449 t, respectively. These surveys were not all conducted at the same time of year and may not be directly comparable; acoustic telemetry has indicated that there is variable timing of migration out of Smith Sound during spring. Low exploitation rates from conventional tagging and high survival rates of acoustically tagged cod indicate that the lower biomass observed during 2009-2011 is not solely due to the combined effects of fishing and natural mortality. The lower biomass more likely reflects a redistribution of some over-wintering cod from Smith Sound to the offshore.

DFO-Industry Bottom-Trawl Survey

This survey was conducted in July-August during 2006-2011 and covered near-shore areas from 15 m to 200 m depth. Catches have generally been higher in the coastal strata (< 50 m depth in particular) and lowest in the northern area. This 6 year time series demonstrates high variability in terms of catch rates and age compositions, with the central and southern areas

influenced by large catches (5-6 t/tow) in some strata. Overall this survey has shown high variability and does not appear to be tracking cohorts and has therefore not proven to be a good index of changes in the stock. Results may be strongly influenced by annual changes in the magnitude and timing of movement of migratory cod from the offshore. This survey was discontinued after 2011.

Biological Information (Inshore)

Changes in stock productivity as measured by growth and condition from sampling of sentinel gillnet catches (1995-2012) are difficult to interpret. The catches may be comprised of fish from different areas and components of the stock. Offshore migratory cod may comprise a larger portion of fish sampled inshore in the recent (~2005-2012) period.

Growth

Length-at-age and weight-at-age at ages 3 and 4 in Div. 3K and Div. 3L declined from the mid-2000s to 2009 but increased marginally in 2010. Length-at-age and weight-at-age among older cod show inconsistent trends and are more variable. Weight at age declined during 2007 to 2009/2010 in ages 6-9 but improved for most ages during 2011-2012.

Condition

Condition of cod, measured using information on length and gutted weight, has shown a general decline since 2005 and values in 2009 and 2010 are among the lowest in the time series (1995-2010), but condition improved in 2011-2012. Condition of cod, measured using information on length and liver weight, is consistently lower in Div. 2J. Condition based on liver weight declined substantially in Div. 3K and Div. 3L from 2008 to 2009. Both measures of condition show slight improvement in 2010-2012.

INDUSTRY PERSPECTIVE

2013 Div. 2J3KL Stakeholders Perspective

The Div. 2J3KL Stewardship Fishery for cod (as prosecuted by commercial fish harvesters) is a limited entry fishery with gear restrictions (amount and type of gear), seasonal and duration restrictions, and landings are closely monitored at sea and at dockside. The data collected by commercial fish harvesters, during their participation in this fishery is very important to the continued monitoring of the recovery of this stock (inshore and offshore).

Fish harvesters feel current catch rates are high with cod, in recent years, being much more widely distributed over inshore and offshore fishing grounds from very shallow depths to depths of 150 fathoms (~275 m). The high abundance and the current distribution of cod resemble historical patterns and is evidence that a significant recovery has and is taking place. Cod condition is excellent.

During the 2012 season, Capelin distribution, migration and the timing of spawning moved closer to historical patterns than in previous years.

Fish harvesters are troubled by the lack of data on the current level of consumption of cod by Harp Seals. More troubling is the complete lack of landings information from the recreational fishery. While it is recognized that the level of mortality caused by seal predation is more difficult to determine, fish harvesters feel that accurate landings information is imperative for the scientific assessment process.

2013 Fish Harvester Questionnaire

Most Div. 2J3KL fish harvesters feel that cod were more abundant in 2012 than in 2011 and in Div. 3K and Div. 3L it is felt that abundance, distribution and the size of cod is better than during the 1980s. While cod condition throughout the area is good, fish harvesters observed low abundance of food fish for cod.

Sources of Uncertainty

There are no direct estimates of recreational landings for 2009-2012. Estimates of removals from recreational fisheries in other years are uncertain. Without accurate estimates of recreational catch, total catch for northern cod remains unknown.

The relative efficiency of the survey trawl at capturing different age groups is uncertain. If the catchabilities differ from the assumed values used in the cohort analysis, stock dynamics may differ from the results presented above.

There is uncertainty in the assumed values for the rate of natural mortality used in estimating exploitation rates from tagging. Although a range of assumed values has been used in some analyses, if the rate of natural mortality changes over time and/or differs from the assumed value this will add uncertainty to the tagging estimates of exploitation rates.

Lower reporting rates of tags add uncertainty to the estimates of exploitation rates from tagging and the analyses of movement patterns and stock structure.

There is a high level of uncertainty surrounding the impact of predators on cod population dynamics.

The estimate of spawning biomass from the acoustic survey in the Bonavista Corridor is based partly on sampling of lengths and weights from two fishing sets. Information from two tows is spatially limited and it is uncertain whether this sampling is representative of the size structure of the whole aggregation which extended over an area of approximately 13,000 km2. This may add uncertainty to the acoustic estimate of spawning biomass.

CONCLUSIONS AND ADVICE

Total catch in 2012 is unknown and in several other years catch is uncertain; there are no methods in place to quantify this uncertainty. A consistent time-series of accurate catch information is needed to evaluate the impact of fishery removals on the stock status. With accurate catch information additional methods of analysis would be available for science to investigate the population dynamics of the stock and provide advice to management.

A conservation LRP has been established for northern cod. Estimated SSB has been well below the LRP since the early 1990s. Although the stock has shown some growth, an expansion of age structure, and improved catch rates especially in the north, the estimate of 2012 SSB is 15 % of the LRP. At current levels of SSB the stock is considered to have suffered serious harm and the ability to produce good recruitment remains seriously impaired. When the stock is at such a low level management actions should focus on promoting further increases in SSB and subsequent recruitment until the stock is more resilient to the effects of fishing.

Overall, the results of this assessment are consistent with the results of the 2011 assessment and 2012 stock update. Current levels of removals have resulted in low exploitation rates and probably have had little impact on recent stock dynamics. However, projections indicate that SSB will not increase during the next four years if total mortality rates (fishing and natural mortality) and recruitment remain at recent levels. In keeping with the DFO fishery decision-making framework incorporating the precautionary approach, removals over the next four years should remain low to promote stock growth.

OTHER CONSIDERATIONS

Management Issues

Recreational fishery

The recreational fishery is likely to be a substantial component of total removals. Improving the management of recreational fisheries is strongly recommended so that total removals can be effectively controlled and directly measured, and more accurate catch information provided to science to evaluate the impacts of fishing.

Ecosystem issues

Both shrimp and Capelin are important prey for cod. Capelin are at a low level but show some positive signs in terms of expansion of distribution, whereas shrimp have declined. A combined low availability of two major forage species in the ecosystem could compromise the potential for recovery of cod in particular, and the groundfish community in general. These community-level implications need to be considered when harvesting is contemplated.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 11-14th, 2013 Stock assessment of Northern (2J3KL) Cod. Additional publications from this meeting will be posted on the *Fisheries and Oceans Canada (DFO) Science Advisory Schedule* as they become available.

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